

Wherefore, what is claimed is:

1. A computer-implemented process for providing a geometric model
5 database for use in a ubiquitous computing environment to respond to queries
about the environment's geometric state, comprising using a computer to
perform the following process actions:

accepting information about the geometric state of the
environment;

10 building a geometric model database of the environment based on
an initial input of said information;

maintaining the geometric model database by modifying it based
on the input of updated information about the geometric state of the
environment; and

15 responding to queries concerning the geometric relationships
between entities in the environment using the geometric model database.

2. The process of Claim 1, wherein the process action of accepting
information about the geometric state of the environment, comprises the actions
20 of:

inputting identifying information from an external source concerning
an object existing in the environment, referred to as an entity, which is to be
included in the geometric model database, said information comprising the
entity's extent which is one of (i) the physical size of the entity, or (ii) the service
25 region of the entity; and

inputting measurements, each of which defines the entity's
relationship to one other entity in the geometric model database.

3. The process of Claim 2, wherein the entity represents a camera and the camera's extent corresponds to a service region constituting a field of view of the camera.

5 4. The process of Claim 1, wherein the process action of building the geometric model database, comprises the actions of:

establishing a set of entities that are of interest in the environment; representing each entity by a coordinate frame and an extent, wherein said extent defines one of (i) the physical size of the entity, or (ii) the service region of the entity; and characterizing the location of each entity in the environment relative to other entities using a measurement defining the entity's relationship to at least one of said other entities.

15 5. The process of Claim 4, wherein the process action of establishing a set of entities, comprises the actions of:

accepting identifying information from an external source concerning an object existing in the environment, referred to as an entity, which is to be included in the geometric model database, said information comprising the entity's extent assigning a unique entity identifier to each entity which is then used by the geometric model database and the external source in referring to the entity; and

making the entity identifiers available to the external source.

25 6. The process of Claim 5, wherein an external source provides more than one extent for an entity, and wherein the process action of assigning a unique entity identifier to each entity, comprises the actions of:

assigning a separate identifier to each entity-extent combination; and

setting the measurement between entity-extent combinations associated with the same entity to zero.

5 7. The process of Claim 4, wherein the process action of representing each entity by a coordinate frame and an extent, comprises a process action of representing each entity by a coordinate frame having a fixed geometric relationship to the physical object associated with the entity.

10 8. The process of Claim 4, wherein the process action of representing each entity by a coordinate frame and an extent, comprises a process action of characterizing an entity's extent as a polygonal region within the environment defined in terms of the entity's coordinate frame whenever the external source provides information as to the shape of the entity's extent.

15 9. The process of Claim 4, wherein the process action of representing each entity by a coordinate frame and an extent, comprises a process action of characterizing an entity's extent as a line segment within the environment defined in terms of the entity's coordinate frame whenever the external source provides information indicating the entity's extent to be such a line segment.

20 25 10. The process of Claim 4, wherein the process action of representing each entity by a coordinate frame and an extent, comprises a process action of characterizing an entity's extent as a point coincident with the origin of the entity's coordinate frame whenever the external source fails to provide information defining a size for the entity's extent.

30 11. The process of Claim 4, wherein the process action of representing each entity by a coordinate frame and an extent, comprises a process action of characterizing an entity's extent as a point having a prescribed geometric relationship to the origin of the entity's coordinate frame.

12. The process of Claim 4, wherein the process action of characterizing the location of each entity in the environment relative to other entities using a measurement defining the entity's relationship to one of said other entities, comprises an action of using a measurement specifying the position and orientation of each other entity's coordinate frame origin in terms of the coordinate frame of the entity under consideration.

13. The process of Claim 4, wherein the process action of characterizing the location of each entity in the environment relative to other entities using a measurement defining the entity's relationship to at least one of said other entities, comprises the actions of:

assigning a unique measurement identifier to each measurement which is then used by the geometric model database and the external source in referring to the measurement defining the entity's relationship to another entity; and

making the measurement identifiers available to the external source.

14. The process of Claim 12, wherein the process action of using a measurement specifying the position and orientation of each other entity's coordinate frame origin in terms of the coordinate frame of the entity under consideration, comprises an action of assigning a spatial uncertainty estimate to the measurement which is indicative of the accuracy of the method used to obtain the measurement.

15. The process of Claim 14, wherein each measurement is provided to the geometric model database by an external source, and wherein more than one measurement defining an entity's relationship to another entity may be provided by separate external sources, and wherein the process action of

Characterizing the location of each entity in the environment relative to other entities using a measurement, comprises an action of, whenever more than one measurement defining an entity's relationship to another entity is received, using only the measurement having the lower uncertainty.

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16. The process of Claim 14, wherein each measurement is provided to the geometric model database by an external source, and wherein more than one measurement defining an entity's relationship to another entity may be provided by separate external sources, and wherein the process action of characterizing the location of each entity in the environment relative to other entities using a measurement, comprises an action of, whenever more than one measurement defining an entity's relationship to another entity is received, arbitrarily choosing one of the measurements for use in characterizing the locations.

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17. The process of Claim 14, wherein each measurement is provided to the geometric model database by an external source, and wherein more than one measurement defining an entity's relationship to another entity may be provided by separate external sources, and wherein the process action of characterizing the location of each entity in the environment relative to other entities using a measurement, comprises an action of whenever more than one measurement defining an entity's relationship to another entity is received, combining said measurements using their relative uncertainties as weights.

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18. The process of Claim 4, wherein the process action of characterizing the location of each entity in the environment relative to other entities using a measurement defining the entity's relationship to one of said other entities, comprises an action of revising the measurements, said revising action comprising the actions of:

inputting a spatial uncertainty estimate associated with each measurement which is indicative of the accuracy of the method used to obtain the measurement;

5 identifying cycles of measurements among the measurements, wherein a cycle of measurements is defined as a string of measurements starting at the origin of a first entity frame in the cycle and following measurements from one entity to the next until reaching a last measurement in the cycle representing the relationship between the coordinate frame of a next to last entity of the cycle and the origin of said first entity frame; and

10 for each cycle identified, computing the difference between a given location of said first entity frame's origin and the location of that origin as indicated by following the chain of measurements making up the cycle;

15 computing revised measurements for the identified cycles by simultaneously adjusting the measurements based on their associated uncertainty estimates so as to make the difference in the given location of said first entity frame's origin in each of the identified cycles match the location of that origin as indicated by following the chain of measurements making up the cycle

20 19. The process of Claim 18, further comprising a process action of repeating the process actions of inputting spatial uncertainty estimates, identifying cycles of measurements, computing the difference between a given location of said first entity frame's origin and the location of that origin as indicated by following the chain of measurements making up the cycle for each cycle identified, and computing revised measurements, whenever new measurements are provided.

25 20. The process of Claim 18, further comprising a process action of repeating the process actions of inputting spatial uncertainty estimates, identifying cycles of measurements, computing the difference between a given 30 location of said first entity frame's origin and the location of that origin as

indicated by following the chain of measurements making up the cycle for each cycle identified, and computing revised measurements, on a periodic basis.

21. The process of Claim 4, wherein the process action of
5 characterizing the location of each entity in the environment relative to other entities using a measurement defining the entity's relationship to at least one of said other entities, comprises an action of detecting errors in the measurements, said error detecting action comprising the actions of:

(a) inputting a spatial uncertainty estimate associated with the
10 measurement which is indicative of the accuracy of the method used to obtain the measurement;

(b) identifying cycles of measurements among the
measurements, wherein a cycle of measurements is defined as a string of measurements starting at the origin of a first entity frame in the cycle and following measurements from one entity to the next until reaching a last measurement in the cycle representing the relationship between the coordinate frame of a next to last entity of the cycle and the origin of said first entity frame; and

(c) 20 for each cycle identified,
computing the location of said first entity frame's origin as indicated by following the chain of measurements making up the cycle, along with computing an uncertainty region around the computed location of the origin based on a combination of the uncertainty estimates associated with each measurement in the cycle,

25 determining if a given location of said first entity frame's origin is within the computed uncertainty region;

whenever the given location falls outside the uncertainty region, declaring that at least one of the measurements in the cycle is incorrect, and

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whenever it is declared that one of the measurements in the cycle is incorrect, disregarding these measurements and requesting that replacement measurements be provided.

5 22. The process of Claim 21, further comprising a process action of repeating process action (c) whenever replacement measurements are provided.

10 23. The process of Claim 21, further comprising a process action of repeating process action (c) periodically.

15 24. The process of Claim 4, wherein the process action of characterizing the location of each entity in the environment relative to other entities using a measurement defining the entity's relationship to one of said other entities, comprises an action of revising the measurements, said revising action comprising the actions of:

(a) inputting a spatial uncertainty estimate associated with each measurement which is indicative of the accuracy of the method used to obtain the measurement;

20 (b) identifying cycles of measurements among the measurements, wherein a cycle of measurements is defined as a string of measurements starting at the origin of a first entity frame in the cycle and following measurements from one entity to the next until reaching a last measurement in the cycle representing the relationship between the coordinate frame of a next to last entity of the cycle and the origin of said first entity frame;

25 (c) for each cycle identified,

30 computing the location of said first entity frame's origin as indicated by following the chain of measurements making up the cycle, along with computing an uncertainty region around the computed location of the origin based on a combination of the uncertainty estimates associated with each measurement in the cycle,

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determining if a given location of said first entity
frame's origin is within the computed uncertainty region,
whenever the given location falls outside the
uncertainty region, declaring that at least one of the measurements in the cycle
5 is incorrect, and

whenever it is declared that one of the measurements
in the cycle is incorrect, disregarding these measurements and requesting that
replacement measurements be provided, and

10 (d) computing revised measurements for those identified cycles
in which the given location of the origin is not the same as its computed location
but in which the given location falls within the uncertainty region by
simultaneously adjusting the measurements based on their associated
uncertainty estimates so as to make the difference in the given location of said
first entity frame's origin in each of the identified cycles match the location of that
origin as indicated by following the chain of measurements making up the cycle.

15 25. The process of Claim 24, further comprising a process action of
repeating process actions (a) through (d) whenever new measurements are
provided.

20 26. The process of Claim 24, further comprising a process action of
repeating process actions (a) through (d) periodically.

25 27. The process of Claim 4, wherein the process action of responding
to queries concerning the geometric relationships between entities in the
environment, comprises an action of, upon receiving a request from an external
source to identify the extent of a particular entity, providing the extent
information to the external source.

28. The process of Claim 4, wherein the process action of responding to queries concerning the geometric relationships between entities in the environment, comprises the actions of:

- waiting for incoming queries from external sources for requests concerning the relative geometric relationship between two entities;
- whenever a request concerning the relative geometric relationship between two entities is received, determining if a direct measurement exists between the two entities involved in the request;
- whenever said direct measurement exists, providing information concerning the measurement to the external source making the request.

29. The process of Claim 4, wherein the process action of responding to queries concerning the geometric relationships between entities in the environment, comprises the actions of:

waiting for incoming queries from external sources for requests concerning the relative geometric relationship between two entities; whenever a request concerning the relative geometric relationship between two entities is received, determining if a direct measurement exists between the two entities involved in the request; whenever said direct measurement does not exist, employing a breadth-first search to find a measurement path between the two entities involved in the request that has the fewest number of measurement links, wherein a measurement path is a chain of measurements from a first of the two entities involved in the request, through at least one intermediate entity, to the other entity involved in the request;

computing the requested measurement information using the measurements in said measurement path, if one was found; and providing the computed measurement information to the external source making the request.

30. The process of Claim 29, wherein the process action of responding to queries concerning the geometric relationships between entities in the environment, further comprises, whenever as a result of employing the breadth-first search more than one measurement path is discovered having the same fewest number of measurement links, randomly choosing one of the discovered measurement path for use in computing the requested measurement information.

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31. The process of Claim 29, wherein the process action of using a measurement specifying the position and orientation of each other entity's coordinate frame origin in terms of the coordinate frame of the entity under consideration, comprises an action of assigning a spatial uncertainty estimate to the measurement which is indicative of the accuracy of the method used to obtain the measurement, and wherein the process action of responding to queries concerning the geometric relationships between entities in the environment, further comprises, whenever as a result of employing the breadth-first search more than one measurement path is discovered having the same fewest number of measurement links, choosing the discovered measurement path exhibiting a lowest combined uncertainty for use in computing the requested measurement information.

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32. The process of Claim 4, wherein the process action of responding to queries concerning the geometric relationships between entities in the environment, comprises the actions of:

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inputting incoming queries from external sources for requests to find entities whose extents have a particular geometric relationship to a prescribed region or extent associated with a specified entity

ascertaining the relative geometric relationship between the frame origin of the specified entity and the frame origins of other entities

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transforming the coordinates of the extents associated with the other entities into the coordinate frame of the specified entity using the

respective relative geometric relationships between the frame origin of the specified entity and the frame origins of said other entities;

5 employing a region intersection procedure to determine if the extents associated with said other entities intersect the prescribed region or extent associated with the specified entity; and

10 providing information to the requesting source as to whether the extents of any of said other entities intersect the prescribed region or extent of the specified entity, and if so which of the other entities' extents intersect.

15 33. The process of Claim 4, wherein the prescribed region or extent associated with the specified entity, as well as the extents associated with said other entities, are characterized by polygonal areas, or degenerated version thereof constituting a line segment or point, and wherein the region intersection procedure is a polygon intersection procedure.

20 34. The process of Claim 1, wherein the process action of responding to queries concerning the geometric relationships between entities in the environment, comprises an action of, upon receiving a standing request from an external source, responding to the request each time a prescribed event occurs.

25 35. A system for providing a geometric model database for use in a ubiquitous computing environment to respond to queries about the environment's geometric state, comprising:

at least one general purpose computing device; and

a computer program comprising program modules executable by the computing device or devices, wherein the computing device or devices are directed by the program modules of the computer program to,

input information about the geometric state of the environment from at least one external source,

establish a set of entities that represent objects in the environment based on an initial input of said information, represent each entity by a coordinate frame and an extent, wherein said extent is based on an initial input of said information, characterize the location of each entity in the environment relative to other entities using a measurement defining the entity's relationship to at least one of said other entities.

36. The system of Claim 35, further comprising:
10 a program module for storing as initializing data in a non-volatile
initializing database, information concerning the entities, their extents, and the
measurements between entities contained within the geometric model database;
and wherein,

the program module for inputting information about the geometric state of the environment, comprises an action of inputting the stored initializing data from the non-volatile database at the start of said process for providing a geometric model database.

37. The system of Claim 36, wherein the program module for storing initializing data, comprises a sub-module for storing only information concerning entities, extents, and measurements that is anticipated not to change substantially over time.

38. The system of Claim 37, wherein the program module for inputting
information about the geometric state of the environment, comprises a sub-
module for inputting update information characterizing a current geometric state
of the environment.

39. The system of Claim 38, wherein the program module for storing
30 initializing data, comprises a sub-module for storing information concerning the

entities, their extents, and the measurements representative of the most current geometric state of the environment.

40. The system of Claim 36, wherein the program module for establishing a set of entities comprises a sub-module for assigning a unique entity identifier to each entity entered into the geometric model database, which is then used by the geometric model database and external sources in referring to the entity, and wherein the program module for characterizing the location of each entity in the environment relative to other entities using a measurement comprises a sub-module for assigning a unique measurement identifier to each measurement entered into the geometric model database, which is then used by the geometric model database and the external sources in referring to the measurement.

15. 41. The system of Claim 40, wherein the program module for storing initializing data, further comprises sub-modules for:

storing the entity and measurement identifiers assigned to the entities and measurements comprising the initializing data in a non-volatile initializing database; and

20. making the entity and measurement identifiers available to the external sources.

42. A computer-readable medium having computer-executable instructions for providing a geometric model database for use in a ubiquitous computing environment to respond to queries about the environment's geometric state, said computer-executable instructions comprising:

inputting information about the geometric state of the environment from at least one external source,

30. building a geometric model database of the environment based on an initial input of said information, and

maintaining the geometric model database by modifying it based on the input of updated information about the geometric state of the environment.

5 43. The computer-readable medium of Claim 42, wherein the
instruction for building the geometric model database, comprises sub-modules
for:
10 establishing a set of entities representing objects in the
environment;
15 representing each entity by a coordinate frame and an extent; and
characterizing the location of each entity in the environment
relative to other entities using a measurement defining the entity's relationship to
one of said other entities.

15 44. The computer-readable medium of Claim 43, wherein the
instruction for inputting information about the geometric state of the environment,
comprises a sub-module for inputting update information characterizing a current
geometric state of the environment.

20 45. The computer-readable medium of Claim 44, wherein the
instruction for maintaining the geometric model database, comprises a sub-
module for updating the geometric model database on an on-going basis, using
the inputted update information characterizing a current geometric state of the
environment, to ensure to the best degree possible given the update information,
25 that only entities currently existing in the environment and their associated
current extents are included in the database, and that measurements between
the current entities are representative of the current geometric relationships
between the current entities.

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46. The computer-readable medium of Claim 45, wherein the sub-module for establishing a set of entities, comprises sub-modules for:

5 assigning a unique entity identifier to each entity entered into the geometric model database, which is then used by the geometric model database and external sources in referring to the entity; and

making the entity identifiers available to the external sources.

47. The computer-readable medium of Claim 46, wherein the sub-module for establishing a set of entities, further comprises a sub-module for deactivating existing entity identifiers associated with entities that are indicated in said update information as no longer being in the environment.

48. The computer-readable medium of Claim 47, wherein the sub-module for characterizing the location of each entity in the environment relative to other entities using a measurement, comprises sub-modules for:

10 assigning a unique measurement identifier to each measurement entered into the geometric model database, which is then used by the geometric model database and external sources in referring to the measurement; and

making the measurement identifiers available to the external sources.

49. The computer-readable medium of Claim 48, wherein the sub-module for deactivating existing entity identifiers associated with entities that are indicated in said update information as no longer being in the environment, comprises sub-modules for:

15 deleting all measurements associated with a deactivated entity from the geometric model database; and

retiring the measurement identifier assigned to any measurement that is deleted for being associated with a deactivated entity.

50. The computer-readable medium of Claim 43, wherein the sub-module for characterizing the location of each entity in the environment relative to other entities using a measurement, comprises sub-modules for:

assigning a unique measurement identifier to each measurement entered into the geometric model database, which is then used by the geometric model database and external sources in referring to the measurement; and

making the measurement identifiers available to the external sources.

51. The computer-readable medium of Claim 50, wherein the sub-module for characterizing the location of each entity in the environment relative to other entities using a measurement, further comprises sub-modules for:

whenever a new current measurement is provided in said inputted update information, using it to replace the corresponding measurement already existing in the geometric model database; and

assigning the measurement identifier associated with the existing measurement to the new current measurement.